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HIGH-VELOCITY-IMPACT TESTS CONDUCTED WITH POLYETHYLENE TEREPHTHALATE PROJECTILES AND FLEXIBLE COMPOSITE WALL PANELS

by Jerry G. Williams
Langley Research Center
Hampton, Va. 23365

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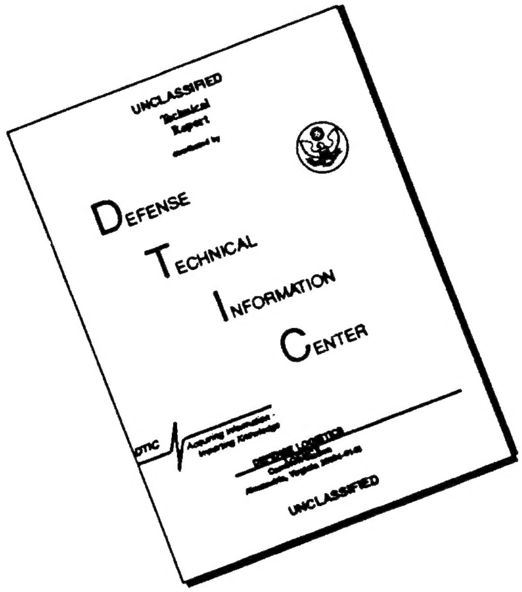

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16. Abstract

Test results are presented for the high-velocity impact of 11 mg, 6.4-millimeter-diameter polyethylene terephthalate disk projectiles fired into flexible composite wall panels. Test panels were composed of various flexible fabric, film, and foam materials including polyethylene terephthalate, nylon, fiber glass, fluorinated ethylene propylene, steel wire, rayon, fluoroelastomer, polyurethane, and neoprene. Test velocities ranged from 2.07 to 5.79 km/sec.

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HIGH-VELOCITY-IMPACT TESTS CONDUCTED WITH POLYETHYLENE TEREPHTHALATE PROJECTILES AND FLEXIBLE COMPOSITE WALL PANELS

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SUMMARY

Test results are presented for the high-velocity impact of 11 mg, 6.4-millimeter-diameter polyethylene terephthalate (PETP) disk projectiles fired into flexible composite wall panels. The projectile velocity for these tests ranged from 2.07 to 5.79 km/sec. Test results indicate that for this velocity range, a low-weight flexible composite wall can be designed which will resist the penetration of a particle with these characteristics without damage to the inner structural and pressure bladder subelements.

INTRODUCTION

Spacecraft for extended manned space missions require cabin wall systems which provide protection against the space environment. The shield (or bumper) concept for providing micrometeoroid impact protection was first proposed by Whipple (ref. 1) and is currently planned for use in most spacecraft designs. The principle of operation of the bumper, which is separated a finite distance from the spacecraft main wall, is to fragment the impacting projectile into many smaller particles. This array of fragmented particles expands over a much larger surface area than the frontal area of the original projectile. The meteoroid bumper effectively reduces the momentum and energy loading per unit area on the main wall. Such double-wall systems are more effective on a weight per unit area basis than single-walled systems in providing protection against high-velocity meteoroid impact. (See ref. 2.)

Studies of the advantages of using the bumper concept is well established in the literature for metallic wall elements. (See refs. 3 to 8.) The meteoroid protection offered by similar flexible wall elements, however, is not nearly so well defined and only a limited number of papers are available in the literature on this subject. (See refs. 9 to 11.) Flexible wall structures are of interest because of their potential utilization in a number of auxiliary manned spacecraft applications. (See refs. 12 to 16.)

The purpose of this paper is to provide additional information on the resistance of the wall to penetration by a high-velocity particle impacting a wall element typical of the type proposed for expandable structures. A typical cross section for the wall of one of these structures is presented in figure 1. The subelements include an outer thermal control coating, meteoroid bumper, low-density spacer of flexible foam, main-wall structural member, pressure bladder, and flame barrier. A description of the design and function of each of these subelements may be found in reference 17. A satisfactory design from a meteoroid-protection viewpoint is one which resists the penetration of a meteoroid without damage to the inner structural and pressure bladder subelements.

The specimens tested in the current investigation were composed of a flexible cloth or film outer layer (which acts as the bumper), a layer of flexible open-celled polyurethane foam, and a flexible cloth or film main wall. The expandable structures material technology is continually being updated and the materials used in this study do not necessarily represent the latest proposed flexible composites. They are, however, typical of the weights, thicknesses, and composite wall configurations currently being considered.

SYMBOLS

The data were obtained in the U.S. Customary Units but are presented in the International Units (SI).

t	thickness, cm
W	weight per unit area, N/m^2
ρ	density, kg/m^3

MATERIAL DESCRIPTION

Various flexible fabric and film materials were used as the bumper and main wall of the test panels of this investigation including polyethylene terephthalate (PETP), nylon, fiber glass, fluorinated ethylene propylene (FEP), steel wire, rayon, fluoroelastomer, polyurethane, and neoprene. The bumper and main wall elements of these specimens were separated a distance ranging from 2.29 to 5.59 cm by a layer of open-celled flexible polyurethane foam. These three subelements were bonded together by use of either polyurethane, polyester, or silicone rubber adhesive. The density of the foam ranged from 16 to 32 kg/m^3. The weight per unit area of the bumper subelement alone ranged from 2.01 to 15.6 N/m^2.

ACCELERATORS AND PROJECTILES

An exploding foil gun was used to accelerate the polyethylene terephthalate (PETP) disk projectile. A description of the exploding foil gun and associated velocity-measuring equipment is presented in reference 18. A discussion of the exploding foil gun technique can be found in reference 19. The 6.4-mm-diameter PETP disk projectile used in these tests was 0.25 mm thick, had a mass of 11 mg, and was accelerated to velocities up to 5.79 km/sec. The density of PETP is 1380 kg/m^3.

RESULTS AND DISCUSSION

Penetration data for the impact of a 0.25-mm-thick, 6.4-mm-diameter PETP disk having a mass of 11 mg into selected flexible composite wall specimens is presented in table I. Data in the table are presented for the damage sustained by the bumper, foam, and main-wall subelements and the total damage to the composite wall. Velocities in the study ranged from 2.07 to 5.79 km/sec.

One of two phenomena characterizes the impact of the projectile with the specimen bumper wall: (1) the projectile remains intact, or (2) the projectile is fragmented. When the projectile remains intact, minimum lateral damage occurs and a long cylindrical damage path approximately equal to the diameter of the projectile results. When the projectile is fragmented, the resulting particles "fan out" from the point of impact and inflict lateral damage to the wall elements. Also, considerable heat is developed as evidenced by the black char left in the foam. Since the energy of impact is dissipated in lateral damage, the depth of penetration is effectively reduced. An illustration of the two types of damage may be seen in figures 2 and 3, which are photographs of the damage to the bumper and cross section of a typical specimen caused by the impact of the PETP projectile. Characteristically, the intact projectile type of damage occurs at low velocities (less than 2.7 km/sec) and the fragmented projectile type of damage occurs at velocities in excess of 4.6 km/sec; between these two velocities, there is a transition region in which partial fragmentation occurs.

Figure 4 presents photographs of the damage to the bumper and main wall of specimen number 36. It illustrates the penetration of a specimen in which the initial contact of the projectile is with a low-density foam bumper. The projectile was partially fragmented by the foam bumper subelement as evidenced by the lateral damage to the foam.

Specimens number 19 and 20 had identical bumper and main wall materials and were impacted at approximately the same velocity. The density of the foam of specimen number 20 (32.0 kg/m^3), however, was twice the density of the foam of specimen

number 19 (16.0 kg/m^3). The penetration results show that the projectile penetrated to a slightly greater depth in the denser specimen. The lateral damage to the denser foam was confined to a smaller radius, as can be seen by comparing the cross sections of the damage to the two specimens as shown in the photographs of figure 5. The total weight per unit area penetrated was thus considerably greater for the denser foam specimen.

A combination of a bumper wall, a thick layer of polyurethane foam, and a main wall was sufficient in nearly all these tests to absorb the energy of the projectile without penetration of the main wall. Maximum depth of penetration was found to vary slightly with orientation of the projectile at impact. For example, the PETP disk orientation at impact into specimen number 15 was on its edge, as indicated by the slit-type hole in the bumper wall. (See fig. 2(a).) Edge-type impact was also observed in specimens number 1, 4, 6, 7, 21, 29, and 34.

A plot of the variation of total weight per unit area penetrated by the PETP projectile with impact velocity for the specimens described in table I is presented in figure 6. The total weight per unit area penetrated varied from 9.6 to 33.5 N/m^2 and with the exception of three tests (specimens number 2, 4, and 21), it was less than 23 N/m^2. As a group, the specimens with bumpers weighing from 2 to 7 N/m^2 in combination with a foam spacer having a density of either 16 kg/m^3 or 20.8 kg/m^3 exhibited the lowest total weight per unit area penetrated. These values do not, in most cases, include the weight of the main wall, since for most tests there was no apparent damage to it. In fact, in only three of the tests (specimens number 2, 4, and 38) did the projectile totally penetrate the main wall. Its role, however, in resisting penetration cannot be ignored and it must be included (as well as the weight of other subelement components, see fig. 1) in any realistic estimate of spacecraft wall weight.

CONCLUDING REMARKS

The data of this paper indicate that a flexible composite wall can be designed which will protect the interior structural and pressure layers against particle impact from a 11 mg, 6.4-mm-diameter PETP disk projectile impacting at velocities up to 5.6 km/sec. In particular, the combination of a bumper weighing from 2 to 7 N/m^2 in combination with a foam spacer having a density of around 20 kg/m^3 can provide low-weight protection against impacts of this type. Fragmentation of the projectile in these tests due to penetrations of the bumper initiated at velocities between 2 km/sec and 4.6 km/sec. Further study of this type of wall configuration with other types of projectiles (such as spheres)

is needed to determine how well this combination protects against higher density and differently shaped particles. Particles with higher velocity should also be considered.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., January 29, 1971.

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TABLE I.- PENETRATION DATA FOR FLEXIBLE COMPOSITE WALLS IMPACTED BY A 0.25-mm-THICK, 6.4-mm-DIAMETER POLYETHYLENE TEREPHTHALATE (PETP) DISK WEIGHING 11 mg

Specimen	Velocity, km/sec	Bumper wall: Material description	Bumper wall: Projectile fragmented by bumper	Bumper wall: Thickness penetrated, cm	Bumper wall: Weight per unit area penetrated, N/m^2	Polyurethane foam spacer: Material description: ρ, kg/m^2	Polyurethane foam spacer: Material description: t, cm	Polyurethane foam spacer: Material description: W, N/m^2	Polyurethane foam spacer: Thickness penetrated, cm	Polyurethane foam spacer: Weight per unit area penetrated, N/m^2	Main wall: Material description	Main wall: Thickness penetrated, cm	Main wall: Weight per unit area penetrated, N/m^2	Total weight per unit area penetrated, N/m^2	Total wall weight per unit area, N/m^2
1	2.07	PETP cloth: t = 0.089 cm W = 6.22 N/m^2 Silicone rubber adhesive: t = 0.038 cm W = 3.35 N/m^2	No	0.127	9.57	23.2	4.07	9.29	4.07	9.29	Fluoroelastomer coated PETP cloth: t = 0.025 cm W = 2.99 N/m^2 Silicone rubber adhesive: t = 0.076 cm W = 6.70 N/m^2	0.0	0.0	18.8	28.6
2	2.13	PETP cloth: t = 0.089 cm W = 6.22 N/m^2 Silicone rubber adhesive: t = 0.038 cm W = 3.35 N/m^2	No	0.127	9.57	23.2	3.94	9.00	3.94	9.00	Fluoroelastomer coated FEP cloth: t = 0.051 cm W = 7.33 N/m^2 Silicone rubber adhesive: t = 0.076 cm W = 6.70 N/m^2	0.127	14.0	[a]33.5	33.5
3	2.13	PETP cloth: t = 0.089 cm W = 6.22 N/m^2 Silicone rubber adhesive: t = 0.038 cm W = 3.35 N/m^2	No	0.127	9.57	23.2	4.07	9.29	4.07	9.29	Fluoroelastomer coated FEP cloth: t = 0.051 cm W = 7.33 N/m^2 Silicone rubber adhesive: t = 0.076 cm W = 6.70 N/m^2	0.0	0.0	18.8	32.9
4	2.16	PETP cloth: t = 0.089 cm W = 6.22 N/m^2 Silicone rubber adhesive: t = 0.038 cm W = 3.35 N/m^2	No	0.127	9.57	23.2	4.07	9.29	4.07	9.29	Fluoroelastomer coated PETP cloth: t = 0.025 cm W = 2.99 N/m^2 Silicone rubber adhesive: t = 0.076 cm W = 6.70 N/m^2	0.101	9.69	[b]31.4	31.4
5	2.35	PETP cloth: t = 0.089 cm W = 6.22 N/m^2 Silicone rubber adhesive: t = 0.038 cm W = 3.35 N/m^2	No	0.127	9.57	23.2	4.07	9.29	2.29	5.27	Fluoroelastomer coated PETP cloth: t = 0.025 cm W = 2.99 N/m^2 Silicone rubber adhesive: t = 0.076 cm W = 6.70 N/m^2	0.0	0.0	14.8	28.6
6	2.38	PETP cloth: t = 0.089 cm W = 6.22 N/m^2 Silicone rubber adhesive: t = 0.038 cm W = 3.35 N/m^2	No	0.127	9.57	23.2	4.32	9.86	4.32	9.86	Two layers PETP cloth: t = 0.051 cm W = 3.54 N/m^2 Silicone rubber adhesive: t = 0.114 cm W = 10.1 N/m^2	0.0	0.0	19.4	33.1
7	2.71	PETP cloth: t = 0.089 cm W = 6.22 N/m^2 Silicone rubber adhesive: T = 0.038 cm W = 3.35 N/m^2	Partially	0.127	9.57	23.2	4.32	9.86	3.18	7.27	Two layers PETP cloth: t = 0.051 cm W = 3.54 N/m^2 Silicone rubber adhesive: t = 0.114 cm W = 10.1 N/m^2	0.0	0.0	16.8	33.1
8	5.18	PETP cloth: t = 0.089 cm W = 6.22 N/m^2 Silicone rubber adhesive: t = 0.038 cm W = 3.35 N/m^2	Yes	0.127	9.57	23.2	4.45	10.12	4.45	10.12	Two layers PETP cloth: t = 0.051 cm W = 3.54 N/m^2 Silicone rubber adhesive: t = 0.114 cm W = 10.1 N/m^2	0.0	0.0	19.7	33.3
9	5.18	PETP cloth: t = 0.089 cm W = 6.22 N/m^2 Silicone rubber adhesive: t = 0.038 cm W = 3.35 N/m^2	Yes	0.127	9.57	23.2	4.32	9.86	4.32	9.86	PETP cloth: t = 0.025 cm W = 1.76 N/m^2 Silicone rubber adhesive: t = 0.076 cm W = 6.70 N/m^2	0.0	0.0	19.4	27.9

[a]Projectile also penetrated 0.89 cm of polyurethane foam bonded to main wall. W = 0.92 N/m^2.
[b]Projectile also penetrated 1.27 cm of polyurethane foam bonded to main wall. W = 2.88 N/m^2.

TABLE I.- PENETRATION DATA FOR FLEXIBLE COMPOSITE WALLS IMPACTED BY A 0.25-mm-THICK, 6.4-mm-DIAMETER POLYETHYLENE TEREPHTHALATE (PETP) DISK WEIGHING 11 mg – Continued

Specimen	Velocity, km/sec	Bumper wall				Polyurethane foam spacer					Main wall			Total weight per unit area penetrated, N/m²	Total wall weight per unit area, N/m²
		Material description	Projectile fragmented by bumper	Thickness penetrated, cm	Weight per unit area penetrated, N/m²	Material description			Thickness penetrated, cm	Weight per unit area penetrated, N/m²	Material description	Thickness penetrated, cm	Weight per unit area penetrated, N/m²		
						ρ, kg/m²	t, cm	W, N/m²							
10	5.18	PETP cloth: t = 0.089 cm W = 6.22 N/m² Silicone rubber adhesive: t = 0.038 cm W = 3.35 N/m²	Yes	0.127	9.57	23.2	4.07	9.29	4.07	9.29	Fluoroelastomer coated PETP cloth: t = 0.025 cm W = 2.99 N/m² Silicone rubber adhesive: t = 0.076 cm W = 6.70 N/m²	0.0	0.0	18.8	28.6
11	5.33	PETP cloth: t = 0.089 cm W = 6.22 N/m² Silicone rubber adhesive: t = 0.038 cm W = 3.35 N/m²	Yes	0.127	9.57	23.2	4.19	9.57	4.19	9.57	Fluoroelastomer coated PETP cloth: t = 0.025 cm W = 2.99 N/m² Silicone rubber adhesive: t = 0.076 cm W = 6.70 N/m²	0.0	0.0	19.1	28.8
12	5.39	PETP cloth: t = 0.089 cm W = 6.22 N/m² Silicone rubber adhesive: t = 0.038 cm W = 3.35 N/m²	Yes	0.127	9.57	23.2	4.19	9.57	4.19	9.57	PETP cloth: t = 0.089 cm W = 6.22 N/m² Silicone rubber adhesive: t = 0.076 cm W = 6.70 N/m²	0.0	0.0	19.1	32.1
13	5.55	PETP cloth: t = 0.089 cm W = 6.22 N/m² Silicone rubber adhesive: t = 0.038 cm W = 3.35 N/m²	Yes	0.127	9.57	23.2	4.07	9.29	4.07	9.29	Fluoroelastomer coated FEP cloth: t = 0.051 cm W = 7.33 N/m² Silicone rubber adhesive: t = 0.076 cm W = 6.70 N/m²	0.0	0.0	18.8	32.9
14	5.79	PETP cloth: t = 0.089 cm W = 6.22 N/m² Silicone rubber adhesive: t = 0.038 cm W = 3.35 N/m²	Yes	0.127	9.57	23.2	4.07	9.29	4.07	9.29	Neoprene coated PETP cloth: t = 0.025 cm W = 2.39 N/m² Silicone rubber adhesive: t = 0.076 cm W = 6.70 N/m²	0.0	0.0	18.8	28.0
15	2.68	Two layers of PETP cloth: each t = 0.025 cm W = 1.75 N/m² Adhesive: t = 0.076 cm W = 6.70 N/m²	No	0.127	10.21	23.2	5.08	11.58	5.08	11.58	Aluminum plate: t = 0.635 cm W = 167.9 N/m²	0.0025	0.67	22.5	189.7
16	5.49	Two layers of PETP cloth: each t = 0.025 cm W = 1.75 N/m² Adhesive: t = 0.076 cm W = 6.70 N/m²	Yes	0.127	10.21	23.2	5.08	11.58	4.19	9.59	Aluminum plate: t = 0.635 cm W = 167.9 N/m²	0.0	0.0	19.8	189.7
17	2.41	PETP cloth: t = 0.025 cm W = 1.76 N/m² Adhesive: t = 0.038 cm W = 3.35 N/m²	Partially	0.063	5.11	23.2	4.96	11.30	4.96	11.30	Aluminum plate: t = 0.635 cm W = 167.9 N/m²	0.0	0.0	16.4	184.4
18	4.60	Laminate of nylon cloth and nylon film bonded with polyester adhesive: t = 0.025 cm W = 2.01 N/m²	Yes	0.025	2.01	16.0	4.83	7.57	4.83	7.57	Oriented layup of steel wire: t = 0.089 cm W = 9.57 N/m² Laminate composite of nylon cloth and film: t = 0.190 cm W = 6.03 N/m²	0.0	0.0	9.6	25.2

TABLE I.- PENETRATION DATA FOR FLEXIBLE COMPOSITE WALLS IMPACTED BY A 0.25-mm-THICK, 6.4-mm-DIAMETER POLYETHYLENE TEREPHTHALATE (PETP) DISK WEIGHING 11 mg – Continued

Specimen	Velocity, km/sec	Bumper wall: Material description	Bumper wall: Projectile fragmented by bumper	Bumper wall: Thickness penetrated, cm	Bumper wall: Weight per unit area penetrated, N/m^2	Polyurethane foam spacer: Material description ρ, kg/m^3	Material description t, cm	Material description W, N/m^2	Polyurethane foam spacer: Thickness penetrated, cm	Polyurethane foam spacer: Weight per unit area penetrated, N/m^2	Main wall: Material description	Main wall: Thickness penetrated, cm	Main wall: Weight per unit area penetrated, N/m^2	Total weight per unit area penetrated, N/m^2	Total wall weight per unit area, N/m^2
19	5.49	Laminate of nylon cloth and nylon film bonded with polyester adhesive: t = 0.025 cm W = 2.01 N/m^2	Yes	0.025	2.01	16.0	4.83	7.57	4.83	7.57	Oriented layup of steel wire: t = 0.089 cm W = 9.57 N/m^2 Laminate composite of nylon cloth and film: t = 0.190 cm W = 6.03 N/m^2	0.0	0.0	9.6	25.2
20	5.61	Laminate of nylon cloth and nylon film bonded with polyester adhesive: t = 0.025 cm W = 2.01 N/m^2	Yes	0.025	2.01	32.0	5.50	17.52	5.59	17.52	Oriented layup of steel wire: t = 0.089 cm W = 9.57 N/m^2 Laminate composite of nylon cloth and film: t = 0.190 cm W = 6.03 N/m^2	0.0	0.0	19.5	35.1
21	2.07	Oriented layup of steel wire: t = 0.089 cm W = 9.57 N/m^2 Laminate composite of nylon cloth and film: t = 0.190 cm W = 6.03 N/m^2	No	0.279	15.60	32.0	5.59	17.52	5.59	17.52	Laminate of nylon cloth and film bonded with polyester adhesive: t = 0.025 cm W = 2.01 N/m^2	0.0	0.0	33.1	35.1
22	2.13	Oriented layup of steel wire: t = 0.089 cm W = 9.57 N/m^2 Laminate composite of nylon cloth and film: t = 0.190 cm W = 6.03 N/m^2	No	0.279	15.60	16.0	4.83	7.57	3.43	5.36	Laminate of nylon cloth and film bonded with polyester adhesive: t = 0.025 cm W = 2.01 N/m^2	0.0	0.0	21.0	22.9
23	2.10	Laminated rayon cloth bonded with urethane resin: t = 0.089 cm W = 6.22 N/m^2	Partially	0.089	6.22	20.8	3.81	7.80	3.81	7.80	Rayon cloth bonded with urethane resin: t = 0.0712 cm W = 3.83 N/m^2	0.0	0.0	14.0	17.9
24	2.13	Rayon cloth bonded with urethane resin: t = 0.64 cm W = 2.97 N/m^2	No	0.064	2.97	20.8	4.19	8.57	4.19	8.57	Rayon cloth bonded with urethane resin: t = 0.0712 cm W = 3.83 N/m^2	0.0	0.0	11.5	15.4
25	2.23	Laminated rayon cloth bonded with urethane resin: t = 0.089 cm W = 6.22 N/m^2	No	0.089	6.22	20.8	4.19	8.57	3.94	8.05	Rayon cloth bonded with urethane resin: t = 0.0712 cm W = 3.83 N/m^2	0.0	0.0	14.3	18.1
26	2.71	Rayon cloth bonded with urethane resin: t = 0.64 cm W = 2.97 N/m^2	No	0.064	2.97	20.8	4.07	8.33	4.07	8.33	Rayon cloth bonded with urethane resin: t = 0.0712 cm W = 3.83 N/m^2	0.0	0.0	11.3	15.1
27	2.71	Laminated rayon cloth bonded with urethane resin: t = 0.089 cm W = 6.22 N/m^2	No	0.089	6.22	20.8	4.07	8.33	4.07	8.33	Rayon cloth bonded with urethane resin: t = 0.0712 cm W = 3.83 N/m^2	0.0	0.0	14.6	18.4

TABLE I.- PENETRATION DATA FOR FLEXIBLE COMPOSITE WALLS IMPACTED BY A 0.25-mm-THICK, 6.4-mm-DIAMETER POLYETHYLENE TEREPHTHALATE (PETP) DISK WEIGHING 11 mg – Concluded

Specimen	Velocity, km/sec	Bumper wall: Material description	Bumper wall: Projectile fragmented by bumper	Bumper wall: Thickness penetrated, cm	Bumper wall: Weight per unit area penetrated, N/m^2	Polyurethane foam spacer: Material description: ρ, kg/m^2	Polyurethane foam spacer: Material description: t, cm	Polyurethane foam spacer: Material description: W, N/m^2	Polyurethane foam spacer: Thickness penetrated, cm	Polyurethane foam spacer: Weight per unit area penetrated, N/m^2	Main wall: Material description	Main wall: Thickness penetrated, cm	Main wall: Weight per unit area penetrated, N/m^2	Total weight per unit area penetrated, N/m^2	Total wall weight per unit area, N/m^2
28	4.97	Laminated rayon cloth bonded with urethane resin: t = 0.089 cm W = 6.22 N/m^2	Yes	0.089	6.22	20.8	4.12	8.43	4.12	8.43	Rayon cloth bonded with urethane resin: t = 0.0712 cm W = 3.83 N/m^2	0.0	0.0	14.6	18.4
29	5.03	Rayon cloth bonded with urethane resin: t = 0.64 cm W = 2.97 N/m^2	Yes	0.064	2.97	20.8	4.07	8.33	4.07	8.33	Rayon cloth bonded with urethane resin: t = 0.0712 cm W = 3.83 N/m^2	0.0	0.0	11.3	15.1
30	5.18	Rayon cloth bonded with urethane resin: t = 0.64 cm W = 2.97 N/m^2	Yes	0.064	2.97	20.8	4.19	8.57	4.19	8.57	Rayon cloth bonded with urethane resin: t = 0.0712 cm W = 3.83 N/m^2	0.0	0.0	11.5	15.4
31	5.33	Laminated rayon cloth bonded with urethane resin: t = 0.089 cm W = 6.22 N/m^2	Yes	0.089	6.22	20.8	4.19	8.57	4.19	8.57	Rayon cloth bonded with urethane resin: t = 0.0712 cm W = 3.83 N/m^2	0.0	0.0	14.8	18.6
32	5.49	Rayon cloth bonded with urethane resin: t = 0.64 cm W = 2.97 N/m^2	Yes	0.064	2.97	20.8	4.19	8.57	4.19	8.57	Rayon cloth bonded with urethane resin: t = 0.0712 cm W = 3.83 N/m^2	0.0	0.0	11.5	15.4
33	5.49	Laminated rayon cloth bonded with urethane resin: t = 0.089 cm W = 6.22 N/m^2	Yes	0.089	6.22	20.8	4.19	8.57	3.94	8.05	Rayon cloth bonded with urethane resin: t = 0.0712 cm W = 3.83 N/m^2	0.0	0.0	14.3	18.1
34	2.34	Fiber-glass cloth: t = 0.025 cm W = 3.52 N/m^2 Silicone rubber adhesive: t = 0.038 cm W = 3.35 N/m^2	No	0.064	6.70	23.2	4.19	9.57	4.19	9.57	Neoprene coated PETP cloth: t = 0.025 cm W = 2.39 N/m^2 Silicone rubber adhesive: t = 0.076 cm W = 6.70 N/m^2	0.0	0.0	16.3	25.4
35	5.21	Fiber-glass c[illegible]: t = 0.025 cm W = 3.52 N/m^2 Silicone rubber adhesive: t = 0.038 cm W = 3.35 N/m^2	Yes	0.064	6.70	23.2	3.94	9.00	3.94	9.00	Neoprene coated PETP cloth: t = 0.025 cm W = 2.39 N/m^2 Silicone rubber adhesive: t = 0.076 cm W = 6.70 N/m^2	0.0	0.0	15.7	24.8
36	5.27	Polyurethane foam: t = 0.025 cm W = 2.87 N/m^2 Neoprene coated PETP cloth: t = 0.025 cm W = 2.39 N/m^2 Silicone rubber adhesive: t = 0.076 cm W = 6.70 N/m^2	Yes	1.372	11.96	23.2	4.19	9.57	4.19	9.57	PETP cloth: t = 0.025 cm W = 1.76 N/m^2 Silicone rubber adhesive: t = 0.038 cm W = 3.35 N/m^2	0.0	0.0	21.5	26.6
37	5.61	Polyurethane foam: t = 0.025 cm W = 2.87 N/m^2 Neoprene coated PETP cloth: t = 0.025 cm W = 2.39 N/m^2 Silicone rubber adhesive: t = 0.076 cm W = 6.70 N/m^2	Yes	1.371	11.96	23.2	4.19	9.57	4.19	9.57	Fiber-glass cloth: t = 0.025 cm W = 3.35 N/m^2 Silicone rubber adhesive: t = 0.038 cm W = 3.35 N/m^2	0.0	0.0	21.5	28.2
38	5.52	FEP film bonded with urethane resin: t = 0.015 cm W = 2.88 N/m^2	Yes	0.015	2.88	23.2	4.19	9.57	4.19	9.57	FEP film: t = 0.0064 cm W = 1.44 N/m^2 Urethane adhesive: t = 0.0165 cm W = 2.86 N/m^2	0.023	4.30	[c]18.7	18.7

[c]Projectile also penetrated 0.89 cm of polyurethane foam bonded to main wall. W = 1.92 N/m^2.

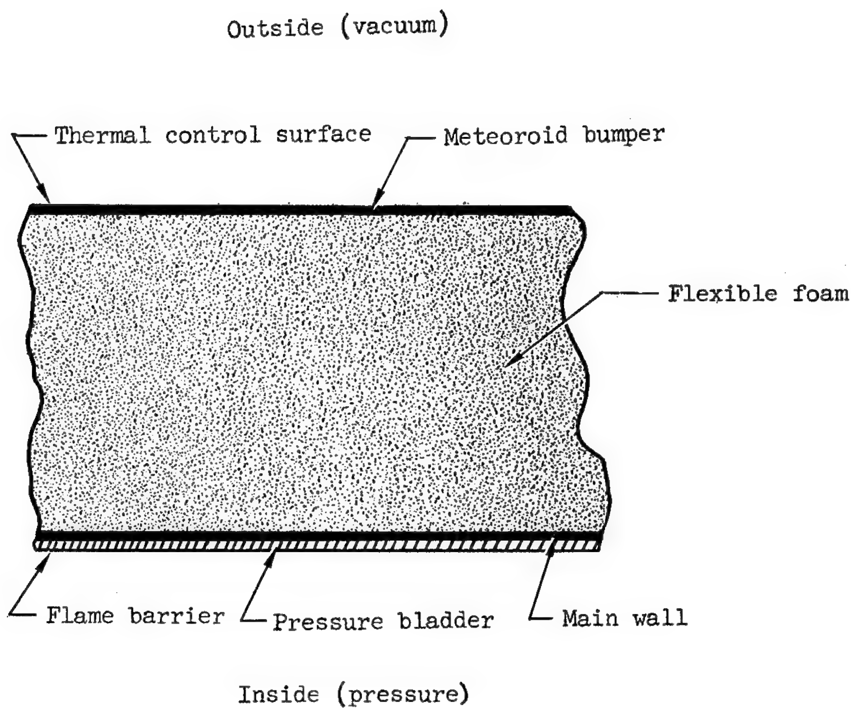
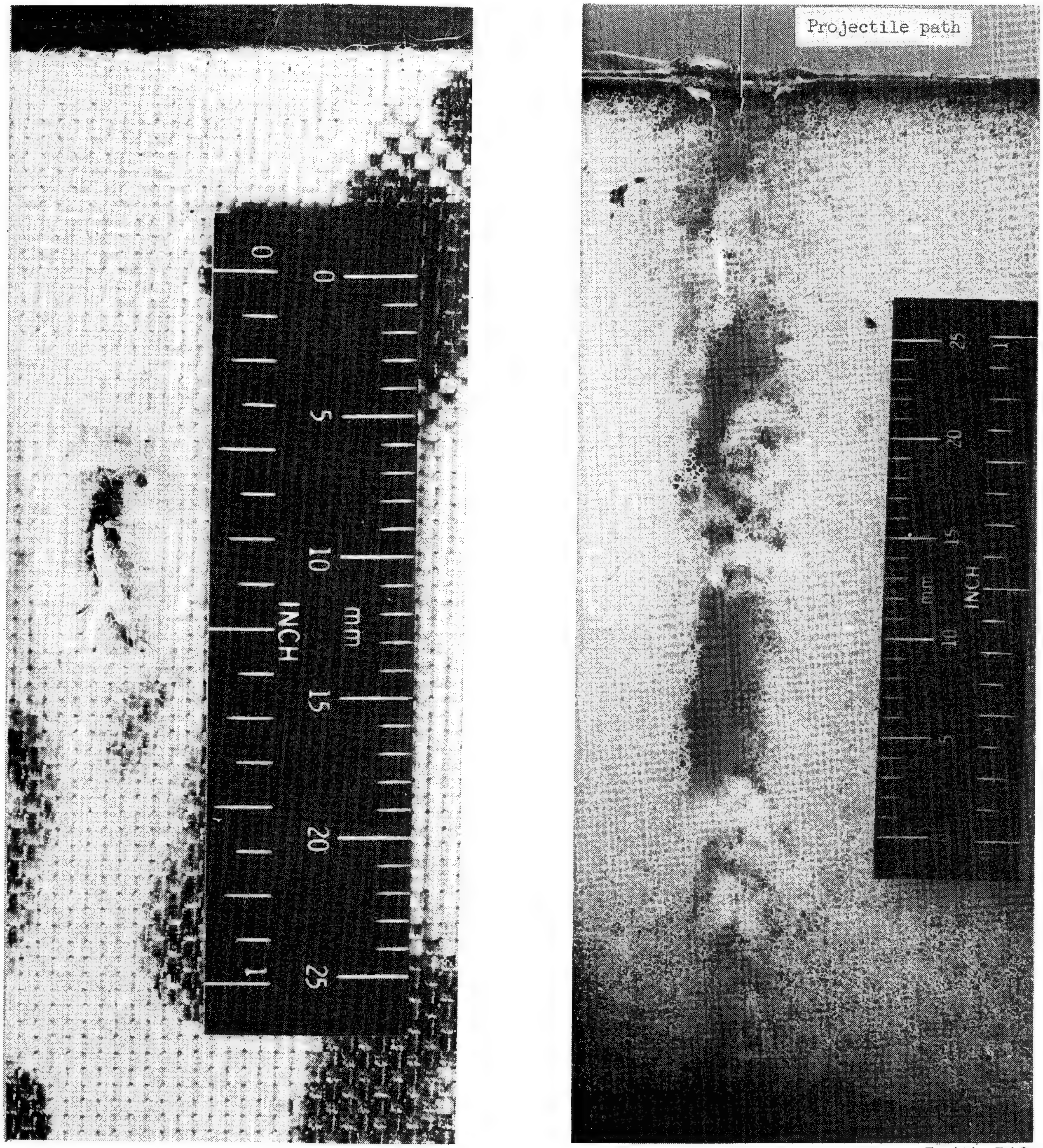


Figure 1.- Typical flexible wall cross section.



(a) Bumper.

(b) Cross section.

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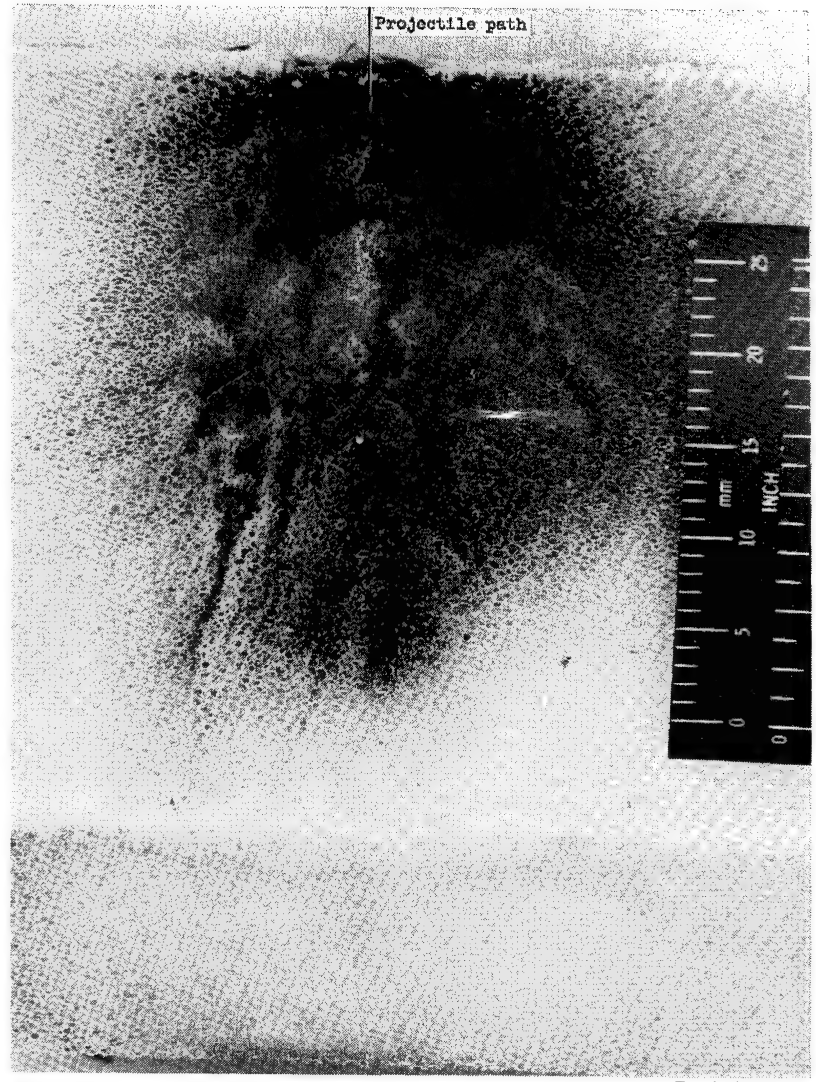
Figure 2.- Typical damage to flexible composite resulting when projectile remains intact. Specimen 15.

(a) Bumper.



(b) Cross section.

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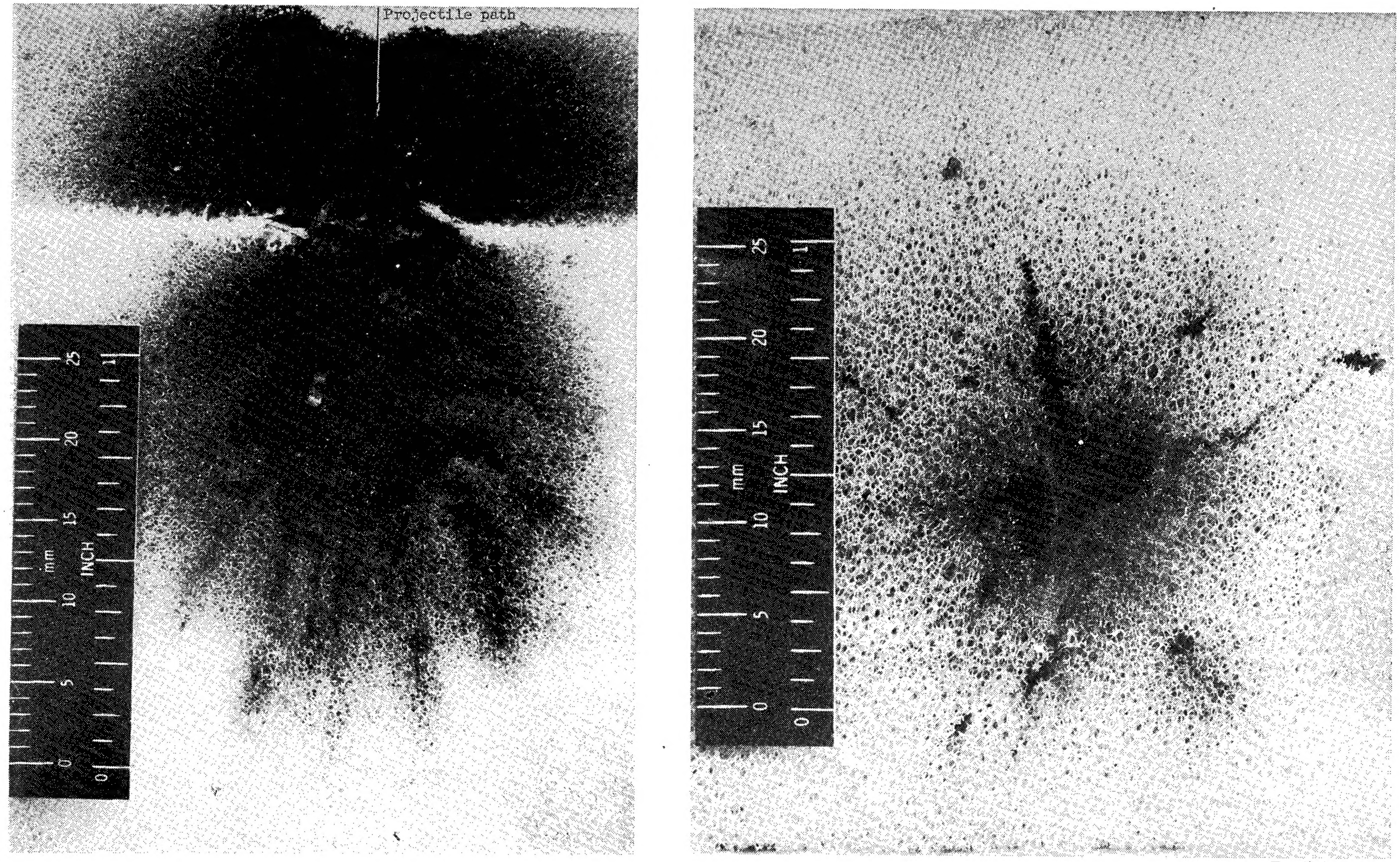
Figure 3.- Typical damage to flexible composite resulting when projectile fragments. Specimen 34.



(a) Bumper.

(b) Cross section.

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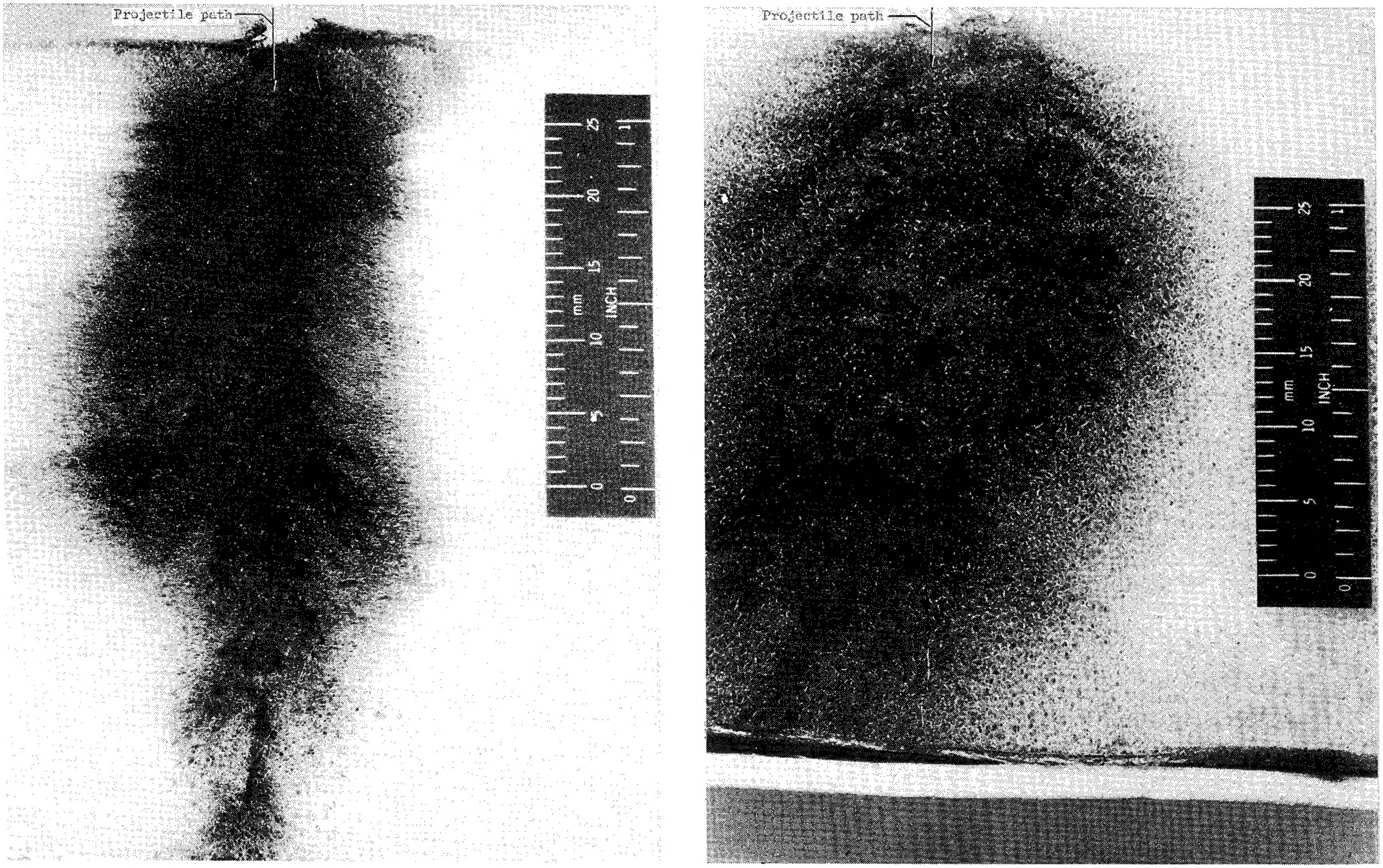
Figure 4.- Impact damage to flexible composite with low-density foam bumper. Specimen 36.



(a) High-density foam. Specimen 20.

(b) Low-density foam. Specimen 19.

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Figure 5.- Penetration damage for specimens with high- and low-density foam fillers.

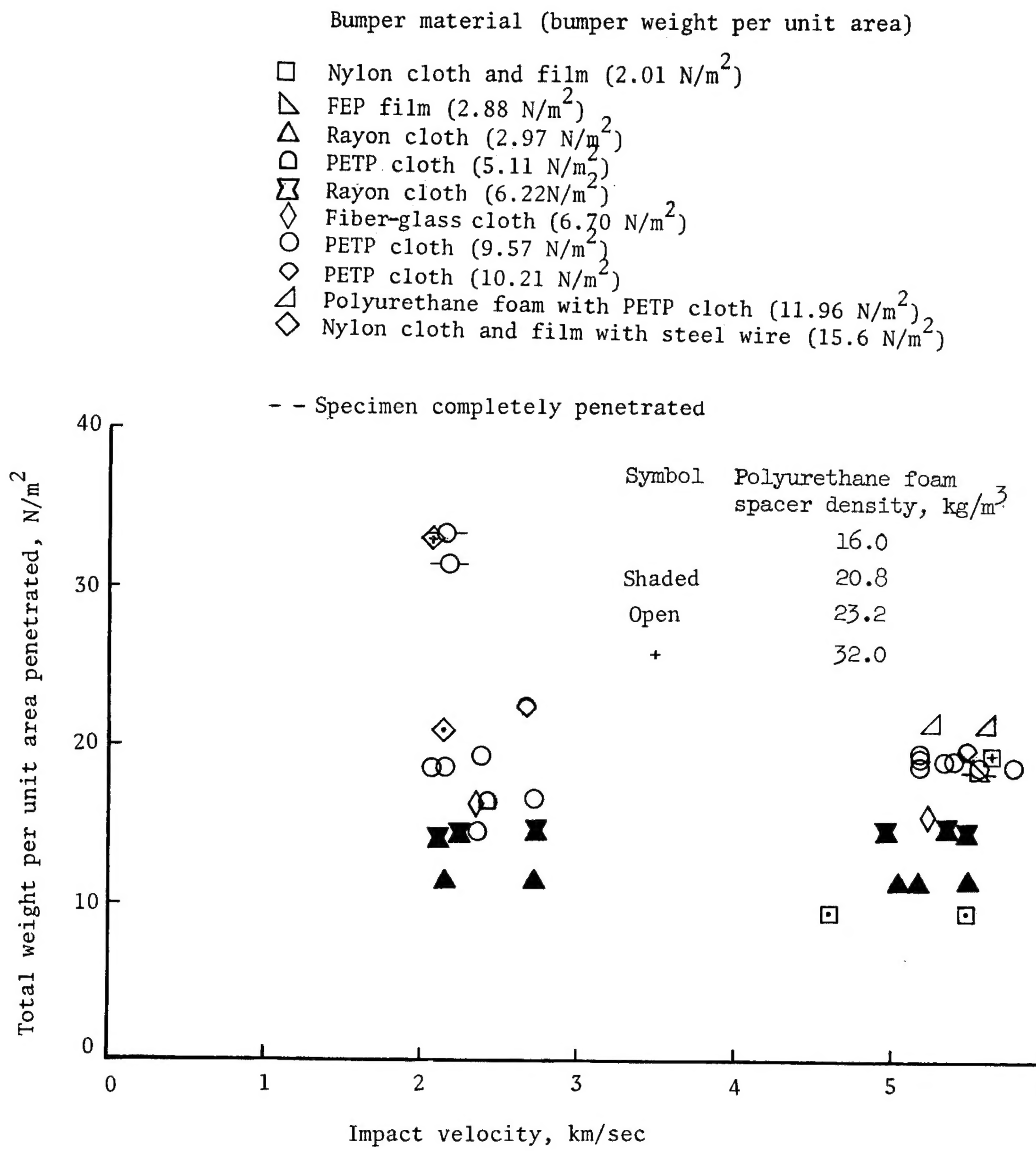

Figure 6.- Variation of weight per unit area of flexible composite wall penetrated by 0.25-mm-thick, 6.4-mm-diameter PETP disk weighing 11 mg with impact velocity.

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